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THE INFLUENCE OF BIORHYTHMIC CRITICALITY ON AIRCRAFT MISHAPS

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THESIS

THE INFLUENCE OF BIORHYTHMIC CRITICALITY
ON AIRCRAFT MISHAPS

by

Dietmar Sacher

September 1974

Thesis Advisor: G. Poock

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Block #20 continued

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Final goal for the application of Biorhythms in that field is considered to obtain a predictive device for operational purposes, reducing the accident rate by avoiding flying days for pilots with disadvantageous criticality states.

The Influence of Biorhythmic Criticality on Aircraft Mishaps

by

Dietmar Sacher
Lieutenant Commander, Federal German Navy

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

ABSTRACT

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I. INTRODUCTION

A. THE PROBLEM

For a long time, since the beginning of industrialization in the Nineteenth Century, it was well accepted that the bottleneck of any system was the machine: high costs, limited availability, technological limitations, and unsatisfactory reliability of its parts and therefore the whole machine constituted severe constraints in the productivity of any system. It was only natural that all concentrated efforts of the industrialized world were devoted to improvements of this "weak link". Mankind proved to be successful in that respect; the only uncomfortable experience, however, was that the man himself had taken over the role of the weak link as machines became better and more complex. People also began to realize that it was a much more complex and sophisticated problem to remove the bottleneck "man" than it had been in the machine's case. What influences his performance in the necessary man-machine interaction? How can one predict his behavior and performance variation in trying to accomplish his task? These were some of the questions man presented in the man-machine interface.

Another drastic change occurred in our attitude toward 'man' and 'machine'. It was only about one hundred years ago that loss of a machine in many parts of the world was considered to be much more severe than loss of a man (worker).

Today we are not only concerned about good performance of the man but also about his safety and his welfare as a human being. Considerations like these led to the question: Being unable to eliminate it, is there any possibility to predict at least the variations in human performance? If we could predict times of 'high' or 'low' performance, relative to a certain (possibly unknown) mean-level, many aspects of human life would be positively affected, making use of this knowledge. One of the numerous attempts to solve this problem was the concept of Biorhythms, first brought up at the end of the Nineteenth Century in Germany and Austria.

B. THE THEORY OF BIORHYTHMS

The concept of Biorhythms claims that each human being is influenced throughout his life by three different cycles, having a different period:

A 23-day period cycle, governing the physical condition.

A 28-day period cycle, governing the emotional condition.

A 33-day period cycle, governing the intellectual condition.

All three cycles can be imagined to have the shape of a sine-wave, having a positive and a negative half-cycle. They all start simultaneously at birth, moving upwards, and continue unchanged through man's life. According to research results in various fields, accidents occur more often on those days where a cycle starts over again, or crosses the "zero-line" on the way from high to low [Ault and Kinkade, 1972; Thommen, 1973; Senzaburo, 1969]. These days are called "critical days".

Consequently, there are three kinds of critical days, depending on how many of the cycles intersect on the axis on a given day. In addition to the already mentioned critical day (one cycle intersects), there is a "double-critical day" (two cycles intersect) and a "triple-critical day" (all three cycles intersect). Even higher accident possibility is predicted for the multiple critical days, especially those involving physical-emotional criticality [Willis, 1972].

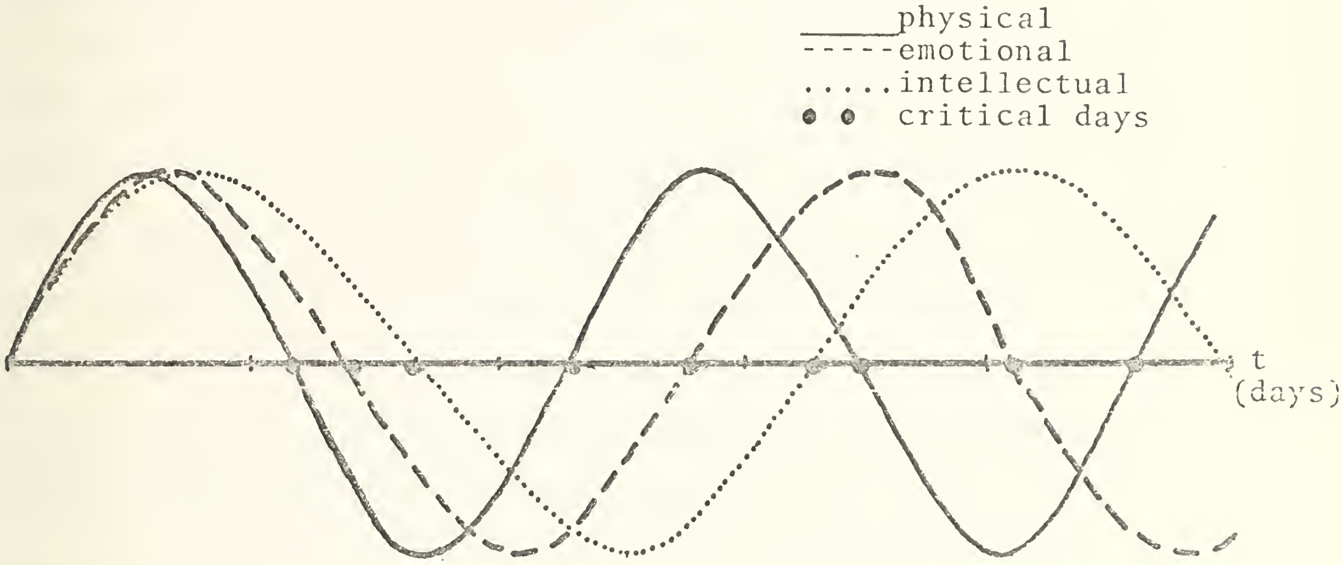

Figure 1. The Three Biorhythmic Cycles (Starting at Birth).

The 23-day physical rhythm has a positive and a negative half cycle of 11.5 days each, indicating better physical condition in the plus period and reduced physical capability in the minus-period. The emotional cycle with a period of 28 days and two 14 day long half cycles, predict optimism and positively influenced emotions during the plus period, emotional instability and pessimistic attitudes during the minus-period.

The intellectual cycle with a period of 33 days and two half cycles of 16.5 days length each are considered to be of minor importance to accidents, having more influence on mental alertness in problem solving and similar tasks.

It must be emphasized that biorhythmic theory does not try to predict absolute "states", it gives only relative classifications like a nominal scale does. That means that one person on a critical day, which is considered to be very disadvantageous still could perform much better in a certain task than another person, having the respective cycle at its maximum, just because of different initial capability. This could very well lead to a point that persons with above average capabilities in reaction time, motor response, etc. are able to avoid an accident in a critical situation, where the majority would have suffered an accident. This point will become important later in the study.

C. HISTORIC BACKGROUND

History books tell us that about 400 B.C. Hippocrates advised his students to observe "good" and "bad" days among the healthy and ill, and to take those fluctuations into consideration in the treatment of the patients.

Between 1897 and 1902, psychologist Dr. Hermann Swoboda (University of Vienna) did some initial research on recurrence of pain and swelling of tissues. Medical review led to the discovery of the 23-day and the 28-day cycle. Also, the first biorhythmic slide rule for determination of the critical days was designed by him.

The nose and throat specialist, Dr. Wilhelm Fliess, M.D., discovered independent from Swoboda these two cycles, based on diagnosis and observations of patients. He called the 23-day cycle the 'masculine', the 28-day the 'feminine' cycle.

The third cycle (intellectual, 33 days) was discovered much later in the 1920's by the engineer, Dr. Alfred Teltscher (University of Innsbruck, Austria). He based his findings on academic performance fluctuations of high school and college students, caused by periodic secretions of glands affecting the brain cells. The same result was obtained by Dr. Rexford Hersey (University of Pennsylvania) in a study using data from workers in railroad shops.

About the same time people began to think about biorhythmic applications in the field of accident research. The mathematicians Dr. Alfred Judt (Bremen, Germany) and H. R. Frueh (Switzerland) had provided the necessary computational tools in form of calculation tables and hand-operated calculators for determination of biorhythmic criticality. In 1939, the first intensive study with a data base of 700 accidents from insurance companies was performed by Hans Schwing, a student at the Swiss Federal Institute of Technology in Zurich, Switzerland [Schwing, 1939]. Schwing came up with the following results: Taking into consideration only the physical and the emotional cycle, he found 401 accidents occurring on critical days, which is about 57%. Of these, 322 fell on single critical days, 74 on double critical days, and 5 on triple critical days. A similar strong significance of biorhythmic criticality on accidents was reported by Reinhold Bochow and

Dr. J. Sennewald (Humboldt University, Berlin, [Bochow, 1954]) investigating 497 accidents of workers using agricultural machinery. Of these, 26.6% of the accidents occurred on single critical days, 46.5% on double critical days, 24.7% on triple critical days, and only 2.2% on non-critical days. The only known accident investigation in the field of aviation based on biorhythmic theory was performed with a data base obtained from the Guggenheim Aviation Safety Center, Cornell University, involving private pilots. Of the observed accidents, 80% occurred on critical days of the pilot [Thommen, 1973].

In the past twenty years, numerous private and government institutions and businesses have made use of the Theory of Biorhythms in connection with accident prevention, especially in Japan, Switzerland, and West Germany. Nothing is known about research and application of this theory behind the iron curtain, except that extensive literature fell into Russian hands after World War II, including many of the findings of Dr. Swoboda [Thommen, 1973]. In recent years, several studies at universities in the United States have been reported [Willis, 1972].

Based on these reported results it was felt that the possibility of a significant reduction of accident rates in various military fields justified a thorough research in the matter.

II. PURPOSE

Accident prevention is an important aspect everywhere in the military. Life, welfare, and health of the people are involved as well as the fact that accidents cause high (and possibly unnecessary) costs to the budget. This research investigates the possibility of using biorhythmic criticality for prevention of aircraft mishaps, based on 4,346 aircraft-mishaps which occurred in FY 1968-1973 in the U.S. Navy. It was felt that strong emphasis should be given to the following statement: The research investigated the usefulness and applicability of the biorhythmic concept, as it was found to be applicable by the many scientists and institutions or businesses, mentioned in the Historical Background. It did not try to find reasons and causalities which lead to the phenomenon of biorhythms. Therefore, only the value of it as a predictive tool for people's accident-likelihood as a function of the day was under question.

One of the biggest problems previously in investigating the applicability of biorhythms was the lack of appropriate data; also, it was just about twenty years ago that the availability of the computer and appropriate statistical techniques made it possible to look at sufficiently large sample sizes to answer the question: Do accidents occur by chance, or do they occur (significantly different from chance) according to biorhythmic criticality? The purpose of this

research was to answer this question for the specific category of aircraft-mishaps and the involved pilots.

III. THE MATHEMATICAL MODEL

Assume an aircraft mishap has occurred on a given day. Then, the criticality of this day in terms of the biorhythmic condition of the involved pilot can take on eight different mutually exclusive and qualitatively defined values:

NC = non-critical

P = physical critical

E = emotional critical

I = intellectual critical

PE = double critical physical/emotional

PI = double critical physical/intellectual

EI = double critical emotional/intellectual

PEI = triple critical physical/emotional/intellectual.

According to that, define a random vector $\underline{X}_j = (x_{1j}\ x_{2j} \cdots\cdots x_{8j}) = (\underline{X}_{ij})$ describing the biorhythmic criticality of a given mishap day j, where

$$i \begin{cases} = 1 \equiv NC \\ = 2 \equiv P \\ = 3 \equiv E \\ = 4 \equiv I \\ = 5 \equiv PE \\ = 6 \equiv PI \\ = 7 \equiv EI \\ = 8 \equiv PEI \end{cases}$$

and

$$x_{ij} = \begin{cases} 1 & \text{if the mishap-day } j \text{ has criticality } i \\ 0 & \text{if the mishap-day } j \text{ has criticality other than } i. \end{cases}$$

Then it is possible to compute the probabilities p_i, which are associated with the occurrence of a mishap-day j having criticality i, under the null-hypothesis that aircraft-mishaps occurred by chance and are not influenced by biorhythmic criticality, such that $p_i = P(x_{ij})$.

Assume that in general, a set of n mishaps in form of appropriate data is available (i.e., giving birthday of the pilot and day of the mishap). Then, let

$$x_i = \sum_{j=1}^{n} x_{ij} ,$$

and

$$\underline{X} = \sum_{j=1}^{n} \underline{X}_j = (\underline{x}_i) = (x_1\ x_2 \cdots\cdot x_8),\ j = 1,\ldots.,n.$$

The random vector $\underline{X}$ is distributed according to the multinomial distribution with parameters n and $(p_1\ p_2 \cdots\cdots p_8)$, and the following properties:

RANGE $R_{\underline{X}} = \{(x_1 \ldots. x_8) : x_i = 0,1,\ldots.,n;\ i = 1,2,\ldots.,8;$

$$\sum_{i=1}^{8} x_i = n \} .$$

PROBABILITY MASS FUNCTION

$$p_{\underline{X}}(\underline{x}) = \binom{n}{x_1,\ldots.,x_8} \cdot p_1^{x_1} \cdot p_2^{x_2} \cdots\cdots p_8^{x_8} ;$$

$$= \frac{n!}{\prod_{i=1}^{8} x_i!} \, p_1^{x_1} \cdot p_2^{x_2} \cdots\cdots p_8^{x_8} \quad ;$$

for

$\underline{x} \in R_{\underline{X}}$,

$0 \leq p_i \leq 1$,

$\sum_{i=1}^{8} p_i = 1$,

$\sum_{i=1}^{8} x_i = n$.

MOMENTS: $E[X_i] = n \cdot p_i$; $V[X_i] = np_i q_i$

and $E[\underline{X}] = n(p_1 \; p_2 \; \cdots \; p_8)$.

This model will be referred to as the "base model" later in the study. The distinction seemed to be necessary because several slight modifications in the dimensionality of the vector $\underline{X}$ had to be applied in order to investigate problems involving differently defined categories i'. The modification consisted in these cases of combining appropriate categories i together, thus reducing to less than eight dimensions, but maintaining the distributional characteristics of the model. In general, it always is based on a multinomial distribution of the kind

$$p_{\underline{X}}(\underline{x}) = \binom{n}{x_1 \ldots x_k} p_1^{x_1} \cdot p_2^{x_2} \cdots\cdots p_k^{x_k} \quad ,$$

where

$$\underline{x} \in R_{\underline{X}},$$

$$0 \leq p_i \leq 1;$$

$$\sum_{i=1}^{k} p_i = 1.$$

Whenever this modification has been used, a short explanation about it and the necessary new definitions of the involved parameters have been added. As an example, the random vector $Y = (Y_1\ Y_2\ Y_3\ Y_4)$ describes the criticality of a mishap day in terms of the four mutually exclusive categories: non-critical, single critical, double critical, and triple critical.

Accordingly, $p_i = P(Y_{ij})$, $i = 1,\ldots,4$; $j = 1,\ldots,n$; represents the probability that a mishap day j has criticality i, following the same rationale as the base case, except that now $Y = f(X) \ni Y_1 = X_1$

$$Y_2 = \sum_{i=1}^{4} X_i$$

$$Y_3 = \sum_{i=5}^{7} X_i$$

$$Y_4 = X_8.$$

A. PROBABILISTIC ASPECTS

As already mentioned, the distribution of the random vector $\underline{X}$ (under the Null-Hypothesis of mishaps occurring by chance and unaffected by biorhythms) was multinomial with Probability vector $\underline{p} = (p_1 \ldots\ldots p_8)$. Therefore, the probabilities $p_i =$

$P(X_{ij})$ had to be computed to use this null-distribution in the further statistical analysis. A set theoretic model was employed to obtain this information. Let

A = set of all non-critical days;

B = set of all physical critical days;

C = set of all emotional critical days;

D = set of all intellectual critical days.

Then

$B \cap C$ = set of all double critical days, physical/emotional;

$B \cap D$ = set of all double critical days, physical/intellectual;

$C \cap D$ = set of all double critical days, emotional/intellectual;

$B \cap C \cap D$ = set of all triple critical days.

The basic application of Venn Diagrams might illustrate this.

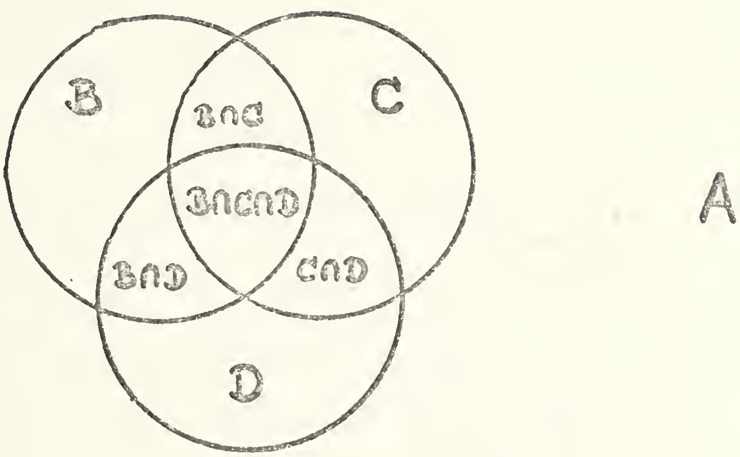

Figure 2. Set-Theoretic Model for the Calculation of the Probability-Vector for the Null-Distribution.

Employing the necessary set theoretic relationships, the elements of the probability vector $\underline{p}$ were obtained as follows:

$$p_1 = P(\text{non-critical})$$
$$= 1 - [P(B) + P(C) + P(D) - P(B \cap C) - P(B \cap D) - P(C \cap D) + P(B \cap C \cap D)].$$

$$p_2 = P(\text{single critical physical})$$
$$= P(B) - P(B \cap C) - P(B \cap D) + P(B \cap C \cap D).$$

$$p_3 = P(\text{single critical emotional})$$
$$= P(C) - P(B \cap C) - P(C \cap D) + P(B \cap C \cap D).$$

$$p_4 = P(\text{single critical intellectual})$$
$$= P(D) - P(B \cap D) - P(C \cap D) + P(B \cap C \cap D).$$

$$p_5 = P(\text{double critical physical/emotional})$$
$$= P(B \cap C) - P(B \cap C \cap D).$$

$$p_6 = P(\text{double critical physical/intellectual})$$
$$= P(B \cap D) - P(B \cap C \cap D).$$

$$p_7 = P(\text{double critical emotional/intellectual})$$
$$= P(C \cap D) - P(B \cap C \cap D).$$

$$p_8 = P(\text{triple critical day}) = P(B \cap C \cap D).$$

The computation of the numerical values of the p_i was based on the following rationale (explained for an example of the 23-day cycle, the others are analogous).

The set B corresponds to all critical days of the 23-day physical cycle. The number of days until the occurence (exclusively) of the next critical day of this type, given it has just occurred, is exactly the length of one half-cycle, namely 11.5 days. Therefore, one out of the 11.5 days in a physical half-cycle is a critical one. Under the assumption

of the Null-Hypothesis that there is no influence from bio-rhythmic criticality, an accident (having occurred) is as likely to have occurred at a critical day as well as on any one of the other days in the half-cycle, thus leading to the idea of a uniform distribution: the probability that the accident occurred on the critical day is just 1/11.5 because the life of any man can be thought of consisting of a large number of these half-cycles, the numerical value will remain unchanged, thus yielding the wanted probability that an accident occurs on a physical critical day by chance.

Event	Set	Length of Half-Cycle(1)	Probability(Set)=1/(1)
Physical	B	11.5	$P(B) = \frac{1}{11.5} = 0.08696$
Emotional	C	14	$P(C) = \frac{1}{14} = 0.07143$
Intellect.	D	16.5	$P(D) = \frac{1}{16.5} = 0.06061$
Phys/Emot	$B \cap C$	11.5 x 14 = 161	$P(B \cap C) = \frac{1}{161} = 0.00621$
Phys/Int	$B \cap D$	11.5 x 16.5 = 189.75	$P(B \cap D) = \frac{1}{189.75} = 0.00527$
Emot/Int	$C \cap D$	14 x 16.5 = 231	$P(C \cap D) = \frac{1}{231} = 0.00433$
Phys/Emot/Int	$B \cap C \cap D$	11.5 x 14 x 16.5 = 2656.5	$P(B \cap C \cap D) = \frac{1}{2656.5} = 0.00038$

Table I. Computation of Probabilities for the Null-Distribution.

Using these results the numerical values of the unknown probability vector could now be computed:

$$\underline{p} = \begin{pmatrix} P(\text{non-critical}) \\ P(\text{single physical}) \\ P(\text{single emotional}) \\ P(\text{single intellectual}) \\ P(\text{double phys./emot.}) \\ P(\text{double phys./int.}) \\ P(\text{double emot./int.}) \\ P(\text{triple critical}) \end{pmatrix} = \begin{pmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \\ p_5 \\ p_6 \\ p_7 \\ p_8 \end{pmatrix} = \begin{pmatrix} 0.79644 \\ 0.07585 \\ 0.06126 \\ 0.05138 \\ 0.00584 \\ 0.00489 \\ 0.00396 \\ 0.00038 \end{pmatrix} .$$

As it should be, $\sum_{i=1}^{8} p_i = 1$. Also, the probability that a mishap falls on a critical day of any type whatsoever is $1 - p_1 = 0.20356$, which is in accordance with the value used in the cited literature and previous research [Thommen, 1973]

B. COLLECTION AND PROCESSING OF THE DATA

The data base consisted of 4346 aircraft mishaps, having been recorded in the fiscal years 1968 through 1973 in the files of the Naval Safety Center, Norfolk, Virginia. The data contained pilot's name, cause code, date of birth, date of mishap, and was stored on magnetic tape. Because of the size of the data set, it would have been impractical and too time consuming to compute the criticality of a mishap day by hand. Therefore, a computer program had to be written to provide this information. The basic idea was to start with the birth

date of the pilot, which caused the j'th mishap, and to find the state of the three cycles at the mishap day. This yielded three numbers, which were compared with the pre-defined criticality definitions, using logical IF-statements. According to this procedure, one of the possible eight criticalities was found to fit and printed behind the name of the pilot (such as "P" for a single critical day physical; if the mishap occurred on a non-critical day, the space provided for this information was left blank). A simple counter then summarized the number of occurrences of each criticality category for the 4346 mishaps.

Presentation of the computer program itself here was not considered to be of importance because of its triviality and the fact that a large portion of it just consisted of the necessary programming procedures for extraction of the relevant data portion from the master tape. More illustrative should be a sample of the actual printout, showing the display of the desired information.

MISHAP ID	CAUSE FACTOR	NAME	BIRTH YR	BIRTH MO	BIRTH DA	TP REC	SSN	BIORHYTHM - FIRST DA OF MISHAP MO P	E	I	* * * * * * ZERO QUAN	SINGLE QUAL	SINGLE QUAN	C R I T I C A L I T Y DOUBLE QUAL	DOUBLE QUAN	* * * * * * TRIPLE QUAL	TRIPLE QUAN
68091730701	1		34	1	17	1		20	19	8	1		0		0		0
68091331101	1		44	6	23	1		5	17	26	1		0		0		0
68091831301	1		36	2	22	1		13	9	1	1		0		0		0
68091910201	1		45	7	29	1		18	8	21	1		0		0		0
68091930401	1		39	8	5	1		18	9	28	1		0		0		0
68091931401	1		42	7	28	1		11	13	29	1		0		0		0
68091931501	1		34	8	28	1		4	20	16	0	I	1		0		0
68091932701	1		34	4	5	1		11	25	29	0	E	1		0		0
68092210101	1		37	12	30	1		3	4	17	0	P	1		0		0
68092310301	1		46	2	7	1		9	11	26	1		0		0		0
68092320501	3		43	8	29	2		5	8	28	0	I	1		0		0
68092320501	1		42	3	5	1		18	18	9	1		0		0		0
68092332001	1		43	8	5	1		6	4	19	1		0		0		0
68092610301	1		40	2	4	1		19	22	10	1		0		0		0
68100110101	1		43	6	4	1		6	12	12	1		0		0		0
68100110201	1		43	1	14	1		9	13	21	1		0		0		0
68100331401	1		44	10	14	1		14	18	9	1		0		0		0
68100432001	1		35	8	23	1		19	26	16	0	E	1		0		0
68100520101	1		30	12	17	1		4	0	10	1		0		0		0
68100920301	1		31	9	4	1		19	19	13	1		0		0		0
68100930201	1		40	7	27	1		13	18	31	1		0		0		0
68100833501	1		30	4	30	1		5	7	10	0		0	P I	1		0

Figure 3. Computer Output Sample.

IV. THE STATISTICAL ANALYSIS

A. THE BASE CASE

The first question to be investigated in the analysis was whether the numerous previous findings in the research about the relationships between biorhythmic criticality and accidents could be supported or not. The critical days of the three cycles had been defined for this purpose in the classical way,[1] as follows:

23-day cycle : Days 1 and 12;

28-day cycle : Days 1 and 15;

33-day cycle : Days 1 and 17.

The computer output yielded the information to find the vector $\underline{X}_o$, showing the number of mishaps which fell into each of the eight categories of criticality:

$$\underline{X}_o = (X_1\ X_2\ \ldots\ldots\ X_8) = (3469\ 315\ 279\ 227\ 28\ 17\ 11\ 0).$$

The appropriate (and for this purpose most powerful) statistical test, to find out whether this observed outcome [illegible] the multinomial distribution under the chance assumption, was the χ^2-Goodness-of-Fit test. If the aircraft mishaps were in fact influenced by biorhythmic criticality, the observed values should differ significantly from the expected ones. If we find, however, that the multinomial distribution with its parameters (computed under the Null Hypothesis that mishaps

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[1] 'Classical way' refers to [illegible] definition used in the previous mentioned rese[illegible]

occur by chance) describes the outcome reasonably well, then it can be concluded that biorhythmic criticality was no important factor contributing to these mishaps.

H_0: $\underline{X} \sim$ Multinomial $(n,\underline{p})$

H_A: H_0 false - biorhythmic criticality causes significantly different mishap occurences.

Criticality	Probability of Occurrence Under H_0, p_i	Number of Mishaps Expected $E[X_i]=n \cdot p_i$	Observed X_i
Non-critical	.7966	3461.34	3469
Single physical	.0760	329.65	315
Single emotional	.0610	266.26	279
Single intellectual	.0510	223.30	227
Double physical/ emotional	.0060	25.36	28
Double physical/ intellectual	.0050	21.27	17
Double emotional/ intellectual	.0040	17.17	11
Triple critical	.0004	1.65	0
	1.00	4346	4346

Table II. χ^2-Test for the Base Case.

For $n \to \infty$ (which could be assumed for $n = 4346$), the asymptotic distribution of

$$V = \sum_{i=1}^{k} \frac{(X_i - n \cdot p_i)^2}{np_i}$$ is χ^2 with $(k-1)$ degrees of freedom.

The level of significance chosen was $\alpha = .10$.

Some problem was caused by one of the requirements of this statistical test: The $E(X_i)$ had to exceed the value of 5, which was violated in the case of expected triple critical days, due to the small probability of occurence of this type of criticality. Statistical theory recommends "grouping together" with another category as a legal and practical procedure, given it makes sense. Therefore, the combination with one of the double-critical categories was considered. It turned out that even when combining in the most sensitive way with the double emotional/intellectual category and thus inflating the value of V, the computed V = 5.72 did not even come close to being significant. The table for the χ^2-distribution shows, for 6 degrees of freedom, the following:

$$\chi^2_6(.25) = 3.454$$

$$\chi^2_6(.75) = 7.841$$

Therefore, the Null-Hypothesis was accepted.

It was felt that some further illustration of the observed result was advisable, especially under the aspect of the findings mentioned in the historic background. Because no information could be obtained about the frequency of occurrence in each of the eight categories, for comparison sake only the classification "critical" and "non-critical" was used, that information being available for all previous research. Employing the applicable binomial model, straightforward application of probability theory yielded the following: Let

$$X = \text{number of mishaps occurring on critical days;}$$

$$n = 4346, \text{ total number of mishaps}$$

$$\left.\begin{array}{l} p = P(\text{critical day}) \\ q = 1 - p = P(\text{non-critical day}) \end{array}\right\} \quad \text{under } H_o$$

Then X is distributed binomial (n,p) with mass function

$$p_X(x) = \binom{n}{p} p^x \cdot q^{n-x}; \; x = 0,1,\ldots.,n.$$

Because the sample size was large enough, the normal approximation could be used, such that

$$Z = \frac{X-\mu_x}{\sigma_x} = \frac{X - np}{\sqrt{npq}}$$

where, Z is normal (0,1) distributed.

Based on this distribution, the probability of an occurence of x = 877 critical day mishaps out of 4346 could be computed using

$$p = 0.20356;$$

$$np = 884.67;$$

$$\sqrt{npq} = 26.54.$$

Applying the continuity correction:

$$z = \frac{(877 + 0.5) - 884.67}{26.54} - 0.27 \; ; \; P(Z>z) = 1-P(Z\leq z)=\underline{0.6064}.$$

Comparing this with the results obtained by Bochow and Sennewald [1954] contradicts their findings in a very drastic manner. They only had 11 out of 497 accidents occurring on non-critical days, corresponding to a z of 42.8 in the normal (0,1)-distribution, a value which is practically 100% significant. (Schwing had looked at the emotional and physical cycle only, so

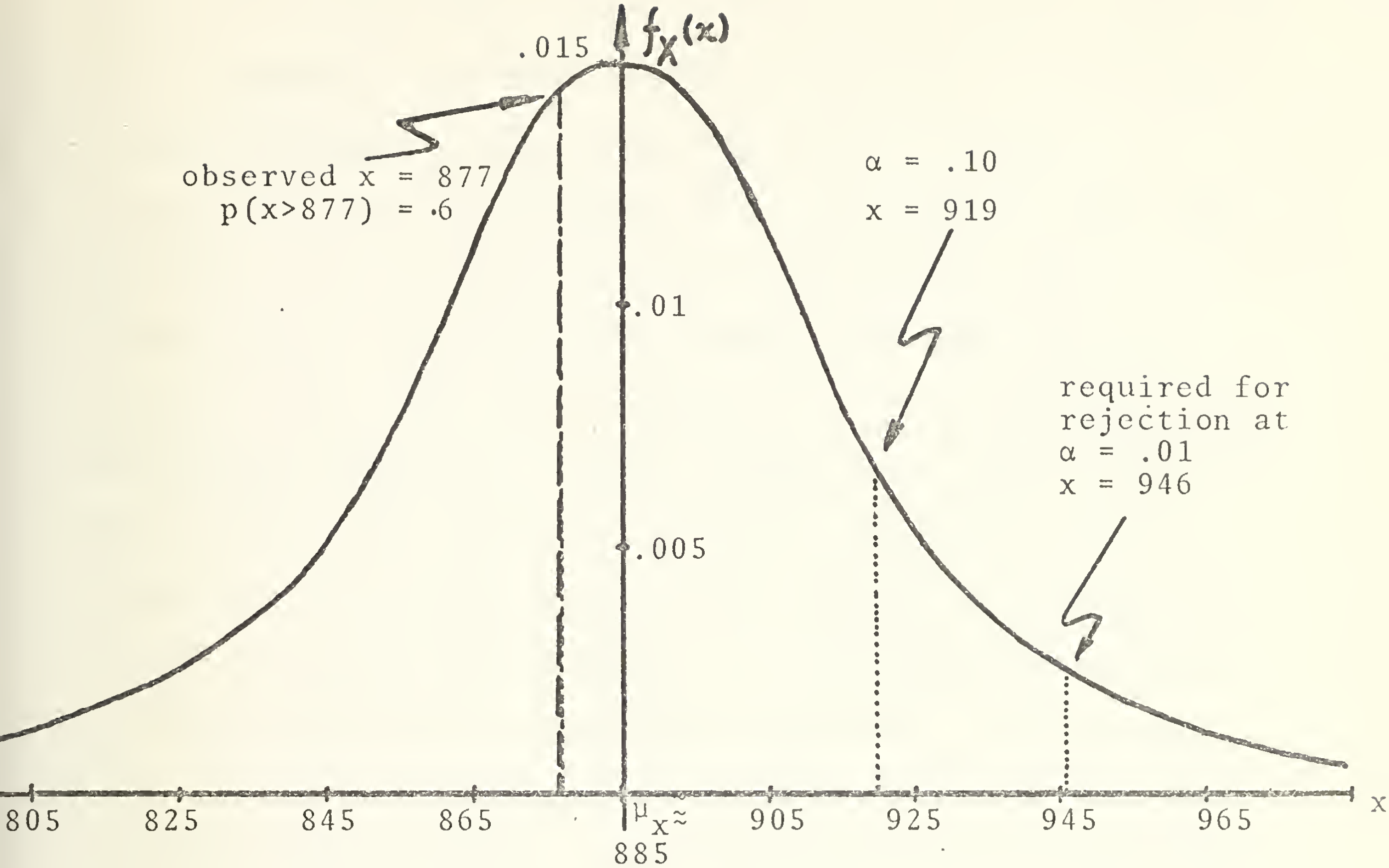


Figure 4. Normal Distribution (Density) for the Base Case.

a comparison with his results will follow under the modifications to this base case.) The striking difference in this comparison required further investigation. The two most reasonable explanations seemed to arise from the fact that the sample size of 497 accidents was not large enough, to yield sufficiently high power, and that a completely different population was used (workers with agricultural machinery). The latter fact gains even more importance under the aspect of a report about the only known study of biorhythmic criticality in connection with military aviation, published by the U. S. Air Force (cited from Thommen, 1973) in March 1972

(Major T. Brady, USAF, editor of TAC Attack; report published by the Department of the Air Force, Headquarters of the Tactical Air Command, Langley Air Force Base, Virginia). A total of 59 aircraft accidents with "pilot only" cause factor were analyzed, and 13 of those occurred on critical days of the pilots. Interestingly enough, 12 would have been expected under the chance assumption, yielding a probability of occurence of 0.52 - a value, supported by the findings of this study. This led to the possible conclusion that because of the characteristics of the population under investigation (pilots), the influence of biorhythmic criticality on human error was in some sense 'overcome'. Pilots are a very special group of people with higher than average capability in many respects: specially selected and fulfilling physical, mental, and intellectual minimum requirements, they might be in better shape at a critical day than some average person on a non-critical, measured on an absolute scale. Furthermore, the dangers of their job-specific tasks are much more apparent than in the every day situation of driving a car, thus reducing the uncertainity of a hazardous event. Finally, pilots are even trained in that respect - their behavior in critical situations is not as random as that of the average person getting involved in a car accident. These considerations led to the necessity of further research, more concentrating on the question, whether pilot's accidents in general are unaffected by biorhythmic criticality, or whether the influence only shows up under different aspects.

Five such aspects were investigated, as shown in the following section under "Modification of the Base Case":

1. Biorhythmic criticality and the pilot's age;

2. Complete elimination of the intellectual cycle. Reason: irrelevance on increased accident-probability, thus masking an effect by the other two cycles (two-cycle model);

3. The influence of the state of the second cycle on a critical day of the first cycle, assuming the two-cycle model;

4. The problem of the "critical category";

5. The question of "accident-type".

B. MODIFICATIONS OF THE BASE CASE

The aspects under which the biorhythmic criticality might influence aircraft mishaps, other than just the critical days as investigated in the last section, are either an increase of criticality, caused by unfavorable states of the other cycles or secondly the elimination of masking effects, or thirdly the categorization of pilots into various groups with common characteristics.

1. Biorhythmic Criticality and the Pilot's Age

Critical days occur due to biorhythmic theory with the same probability throughout human life. However, the effect of those critical days on (in this study) pilots might not be the same for different ages. For example, the emotional criticality could influence younger pilot's much more due to their higher sensitivity than the more stable older pilots.

Similarly, a relatively better physical condition might reduce the influence of physical criticality for younger pilots while having more severe effects on older pilots. After discussions with pilots at the Naval Postgraduate School as well as from the Naval Safety Center in Norfolk, Virginia, the 4346 pilots in the data set were divided into five groups trying to obtain meaningful "cut-off" points. Defining T_j as the age of the pilot in the year of the accident or mishap, respectively, the following age-groups were used:

Group	Interval
1	$T_j \leq 24$ (Years)
2	$25 \leq T_j \leq 29$
3	$30 \leq T_j \leq 34$
4	$35 \leq T_j \leq 39$
5	$40 \leq T_j$.

Again, within each group, there are the eight possible criticality categories as already defined earlier. Again, the Null-Hypothesis to be tested was

$$H_o: \chi \sim \text{Multinomial } (n, \underline{p})$$

$$H_A: H_o \text{ false}$$

with a significance level of $\alpha = .10$. This time, a χ^2-contingency table had to be used, taking 'criticality' as columns and 'age group' as rows. Because the criticality-probabilities were already known under the Null-Hypothesis, these parameters had to be considered as fixed and to be accounted for in the computation of degrees of freedom.

The following results were obtained:

Criticality Group	NC	P	E	I	PE	PI	EI	PEI	Total	$\hat{p}_{i.}$
1	404	28	26	26	4	1	0	0	489	.1125
2	1897	168	156	122	19	10	7	0	2379	.5474
3	579	61	45	34	1	5	1	0	726	.1670
4	418	41	38	35	3	1	2	0	538	.1238
5	171	17	14	10	1	0	1	0	214	.0493
Total	3469	315	279	227	28	17	11	0	4346	
$p_{.j}$	........as computed in the previous analysis									

Table III. χ^2-Contingency Table (5 Age Groups, 8 Criticality Categories).

In order to fulfill the requirements of a χ^2-Goodness-of-Fit test, the terms $e_{ij} = n\hat{p}_{i}.p._{j}$ have to exceed the value 5. The test allows the combining of categories, such that fewer than twenty percent of the cells have $e_{ij} < 5$, and none of them $e_{ij} \leq 1$. These requirements are met when combining the criticality categories PE, PI, EI, and PEI to the new category "MULTIPLE CRITICAL", obtaining the new $p_{.j}$ by just adding the single probabilities of the mutually exclusive combined categories. The contingency table then took on the form shown in Table IV. The test statistic used was

$$V = \sum_{i=1}^{5} \sum_{j=1}^{5} \frac{(X_{ij} - n \cdot \hat{p}_{i} \cdot p._{j})^2}{n \cdot \hat{p}_{i} \cdot p_{.j}}$$

which is approximately χ^2-distributed, with rc - (r-1) = 25 - 4 - 1 = 20 degrees of freedom. $\chi^2_{(20)}(.90) = 28.41$;

$V = 12.2$; because $12.2 < 28.41$, accept the Null-Hypothesis.[2]

	Non-Critical	P	E	I	Multiple Critical
1	404 / 389.46	28 / 37.09	26 / 28.96	26 / 25.13	5 / 7.36
2	1897 / 1894.74	168 / 180.45	156 / 145.75	122 / 122.24	36 / 35.82
3	579 / 578.22	61 / 55.07	45 / 44.48	34 / 37.3	7 / 10.93
4	418 / 428.49	41 / 40.81	38 / 32.96	35 / 27.64	6 / 8.1
5	171 / 170.44	17 / 16.23	14 / 13.11	10 / 11.0	2 / 3.22

Table IV. χ^2-Contingency Table (5 Age Groups, 5 Criticality Categories).

[2]In a general r x c table with r rows and c columns, when testing for independence, there are $r \cdot c-1-(r-1)-(c-1) = (r-1) \cdot (c-1)$ degrees of freedom. In this case, however, the parameters appearing in the rows are the elements of the probability vector of the null-distribution and, therefore, known under H_o. So they do not have to be estimated and the appropriate degrees of freedom are $r \cdot c-1 - (c-1) = rc-c = c \cdot (r-1)$.

Despite this insignificant result, some interesting observations could be made from the interpretation of the contingency table, especially with respect to a "masking effect":

a) The irrelevance of the intellectual cycle in connection with accidents became apparent, supporting Schwing's study, who had eliminated this cycle completely in his model. In fact, the intellectual criticality seemed just to inflate the degrees of freedom, without contributing to the value of V.

b) A similar observation could be made especially for the groups of pilots over 30 years of age. Being older and more experienced, therefore, (a valid assumption in the case of military aviation, but not necessarily in other fields), they were practically uninfluenced by biorhythmic criticality: expected and observed values were extremely close, having the same effect on degrees of freedom and the value of V like the intellectual cycle.

c) So far unexplained are the very small numbers of accidents in some cells, sometimes up to 25% less than the expected values. Many reasonable explanations are possible for this phenomenon, for example, that the bad overall physical days plays the role of a 'warning device'. The lack of capability relative to other days becomes more apparent to the pilot and leads him to even more attention and concentration. It was felt, however, that such considerations were too much in the direction of speculation. A thorough analysis should be left as a topic for further research.

2. <u>Effect of the Elimination of the Intellectual Cycle</u>

In order to have the possibility of a comparison with Schwing's results [1939], who included only the physical and the emotional cycle in his study, the base model was modified in this sense and the probabilities associated with the new criticalities computed. Instead of eight as in the base case, four possible criticalities were accordingly defined:

1. Non-critical;
2. Single critical physical;
3. Single critical emotional;
4. Double critical physical/emotional.

If mishaps occur by chance, the distribution in this case was assumed to be multinomial $(n, (p_1\ p_2\ p_3\ p_4))$ such that $\sum_{i=1}^{4} p_i = 1$. The p_i were computed in the same manner as in the base model and came out to be

$$p_1 = .847826087 \cong .8478$$

$$p_2 = .0807453416 \cong .0808$$

$$p_3 = .0652173913 \cong .0652$$

$$p_4 = .0062111801 \cong .0062.$$

The purpose of this was not to "re-do" the analysis under conditions which look more "promising" as far as rejection of the Null-Hypothesis is concerned, but to compare the findings of this study with the previous ones listed in the historic background.

Running the same type of χ^2-test as in the base case, based on the following table did not show significance as

well, the hypothesis again questioning the multinomial distribution with $\alpha = .10$.

Criticality	p_i	Number of Mishaps Expected	Number of Mishaps Observed
Non-critical	.8478	3684.65	3696
Single physical	.0808	350.92	332
Single emotional	.0652	283.43	290
Double critical emotional/physical	.0062	27.00	26
Total	1.00	4346	4346

Table V. χ^2-Test After Eliminating the Emotional Cycle.

$$V = \sum_{i=1}^{4} \frac{(X_i - np_i)^2}{np_i} = 1.24; \qquad \chi^2_{(3)}\ (.90) = 6.25$$

$$V = 1.24 < 6.25 \Longrightarrow \text{Accept the Null-Hypothesis.}$$

Furthermore, the normal approximation to the binomial distributed random variable X(=number of mishaps occurring on critical days) was applied in the same manner as in the base case. In Schwing's study of 700 accidents, 401 of them occurred on critical days of the people involved. Then

$$p_X(x) = \binom{n}{x} p^x \cdot q^{n-x}, \quad x = 0,1,2,\ldots,n;$$

$$n = 700$$

$$p = P(\text{Critical day}) = p_2 + p_3 + p_4$$

$$= .1522$$

$$q = 1 - p = p_1 = .8478.$$

Because n is large enough, $X \sim N(np, npq)$.

$$P(X>401) = 1 - P(X\leq 401) = 1 - \Phi\left(\frac{(401-.5) - 700\cdot(.1522)}{700\cdot(.1522)\cdot(.8478)}\right)$$

$$= 1 - \Phi(30.93) = 1 - 1 = 0.$$

Like the Sennewald study, this was practically 100% significant in rejecting the hypothesis of chance - occurrence of accidents. In this study, 650 out of the 4346 aircraft-mishaps had occurred on critical days, which was, again, very close to the expected number of about 661. Going through the analogous computations yielded a probability of about .68, associated with this number under the Null-Hypothesis. Being very close to the result obtained in the base-case, the removal of the intellectual cycle had not had any effect. This was not so in re-analyzing the effect of biorhythmic criticality with the two-cycle model, using the results of the last paragraph and applying it to the two age groups of pilots under 30. Testing the Null-Hypothesis of aircraft mishaps occurring by chance against the alternative of biorhythmic criticality influence under the described aspects turned out to show significance. Applying the Goodness-of-Fit test to the contingency table below, the Null-Hypothesis was rejected at the $\alpha = .10$ level of significance.

$$V = \sum_{i=1}^{2} \sum_{j=1}^{4} \frac{(X_{ij} - n\, p_{\cdot j}\, p_i)}{n\cdot\hat{p}_{\cdot j}\cdot p_i} = 8.00;$$

$$df = rc - (c-1) - 1 = 8 - 3 - 1 = 4.$$

$$\chi^2_{(4)}(.90) = 7.78 \Longrightarrow \text{Reject } H_0.$$

Criticality / Age Group	NC	P	E	PE	Total	$p_{.j}$
1	430 / 414.67	29 / 39.61	26 / 31.79	4 / 2.93	489	.17
2	2019 / 2017.39	178 / 192.70	163 / 154.64	19 / 14.27	2379	.83
Total	2449	207	189	23	2868	-
$p_{i.}$	.848	.081	.065	.006	-	1

Table VI. χ^2-Contingency Table (2 Age Groups Under 30 Years, Two-Cycle Model).

It was felt that a short word about the course of the whole analysis should be added here. The situation was very much like the famous search for the needle in the haystack, with the additional difficulty that it was not even sure that there was a needle at all (a significant influence from biorhythmic criticality being the "needle"). If Biorhythms are not affecting military aircraft accidents, every statistical test on the randomness of these occurring should not yield significance, whatever aspect is looked at. If Biorhythms have an effect, there are uncountable factors under which their influence could show up, if it did not in the base model (as it was the case). The problem is similar to the search for an unknown bias of a die: tossing it 4000 times might not show the bias, giving the expected number of each side. The bias might be hidden, showing only up under

certain treatment of the die, as for example a carefully designed inertia effect, favoring fives and sixes only when tossing a longer way, or with a certain strength, etc. There is just no other way of detecting such an influence than testing some of the numerous possibilities and thus "demasking" it by removing the "noise". Without having been added to the study, many of these possibilities had been looked at, like carrier landings only, night landings, mishaps with fatalities, etc., none of which had shown an effect from biorhythmic criticality. The first aspect, showing this influence, was in the just described modification of the base case, looking at the physical and emotional cycle and testing the mishaps of 2868 pilots under thirty years of age, divided into two age groups above and below 25. Biorhythmic criticality was found to have a significant effect on the mishaps at a level of .10, however, with the still unexplained phenomenon of the occurrence of fewer mishaps than expected.

3. Single-Criticality and the State of the Second Cycle in the Two-Cycle Model

It has been pointed out in previous research [Thommen, 1973] that there are some states of the cycles causing even more unfavorable conditions in connection with accidents than just critical days. In the two-cycle model, the state of the second cycle has been claimed to be of importance, given the subject had a critical day in the first cycle. So, for example, a positive state of the emotional cycle on a physical critical day might lead to over-estimation of the current

physical capability. Therefore, the data were evaluated to test the following hypothesis: do aircraft-mishaps occur equally likely on critical days, irrespective of the state of the other cycle?

It was important again to build a model representing the situation under the Null-Hypothesis of biorhythmic irrelevance, i.e., mishaps occurring by chance. This time, two complete cycles were under investigation rather than just their critical days, which required a new model. For that purpose, the state space of the two cycles had to be defined, introducing new notation:

Let the symbol

' 0 ' describe the critical day of a cycle;

' + ' describe the positive half of a cycle;

' - ' describe the negative half of a cycle.

Then, the state of the 23-day and the 28-day cycle together could be described in terms of an ordered pair, the first element being the state of the physical and the second element being the state of the emotional cycle. The state space was therefore to be defined as

$$\mathcal{Q} = \{(0,0),(0,+),(0,-)(+,0),(-,0),(+,+),(+,-),(-,+),(-,-)\}$$

The methodology of computing the probability of each ordered pair occurring was the same as already used in the base model. Before a particular state of the two cycle repeats, a period of 23 times 28 or 644 days elapses. The respective probabilities are then found by application of the uniform property under the Null-Hypothesis, dividing the number of days the

cycles are in that state by the total length of 644 days. Because the intermediate states of the two cycles, where none of them is in a critical state, have not been of particular interest here, these four ordered pairs were combined to a subset called "intermediate states", such that $I = \{(+,+),(+,-),(-,+),(-,-)\}$

The following table gives then the associated probabilities.

$$P[(0,0)] = \frac{56}{644} \cdot \frac{46}{644} = \underline{0.00621118}$$

$$P[(0,+)] = P[(0,-)] = \frac{56}{644} \cdot \frac{299}{644} = \underline{0.0403727}$$

$$P[(+,0)] = P[(-,0)] = \frac{294}{644} \cdot \frac{46}{644} = \underline{0.03269}$$

$$P[(+,-)] = P[(+,+)] = P[(-,+)] = P[(-,-)]$$

$$= \frac{294}{644} \cdot \frac{299}{644} = \underline{0.2119565}$$

		Expected number = n·P State		Observed Number	
State	P [State]	Under 30 Years	30 Years and Older	Under 30 Years	30 Years and Older
(0,0)	.0062	17.81	9.18	23	5
(0,+)	.0404	115.79	59.67	96	66
(0,-)	.0404	115.79	59.67	111	59
(+,0)	.0326	93.52	48.20	95	45
(-,0)	.0326	93.52	48.20	94	56
Intermediate	.8478	2431.57	1253.08	2449	1247
TOTAL	1	2868	1478	2868	1478

Table VII. Observed and Expected Mishaps for Two-Dimensional Criticality States Under the Two-Cycle Model.

It was possible to test the significance of the observed number of mishaps which had occurred on days of a given state, by applying the binomial test and using the normal approximation for large samples. While some states did not show any significant deviation from the expected values, others did. Again, as observed already before, fairly large deviations to both sides of the mean occurred, sometimes in the opposite sense for the two age groups. Computations for the most interesting cases are shown below, where Z = number of mishaps of that state, Z ~ Normal (np,npq)

<u>State (0,0), under 30</u>

Double critical physical, emotional;

$n = 2868;\ p = .0062;\ q = .9938;\ z = 23.$

$$P(z>23) = 1 - P(z\leq 23) = 1 - \Phi\left[\frac{(23-0.5) - 17.81}{4.2}\right] = 1 - \Phi(1.12)$$

$$= \underline{0.13}.$$

<u>State (0,+) under 30</u>

Single critical physical, positive emotional;

$n = 2868;\ p = .04037;\ q = .95963;\ z = 96.$

$$P(z<96) = \Phi\left[\frac{(96+0.5) - 115.79}{10.54}\right] = \Phi(-1.83) = \underline{0.0336}.$$

<u>State (0,0) 30 and older</u>

Double critical physical/emotional;

$n = 1478;\ p = .0062;\ q = .9938;\ z = 5.$

$$P(z<5) = \Phi\left[\frac{(5+0.5) - 9.18}{3.02}\right] = \Phi(-1.22) = \underline{0.11}.$$

<u>State (0,+) 30 years and older</u>

Single critical physical, positive emotional;

$n = 1478$; $p = .04037$; $q = .95963$; $z = 66$.

$$P(z>66) = 1 - P(z \leq 66) = 1 - \Phi\left[\frac{(66-0.5) - 59.67}{7.57}\right]$$

$$= 1 - \Phi(.77) = \underline{0.2206}.$$

<u>State (-,0) 30 years and older</u>

Emotional cycle critical, physical negative;

$n = 1478$; $p = .0326$; $q = .9674$; $z = 56$.

$$P(z>56) = 1 - P(z \leq 56) = 1 - \Phi\left[\frac{(56-0.5) - 48.2}{6.83}\right]$$

$$= 1 - \Phi(1.07) = \underline{0.1423}.$$

The results in connection with the state (0,0)-double criticality--are not new and have been listed just to show the discrepancy between the age groups under that aspect. New insights were gained by the analysis of the other states above, leading to the following conclusions:

a) For pilots under thirty years of age, significantly less mishaps occurred on physical critical days, when the emotional cycle was positive (significant at the .05 level). This supports the theory of the emotional cycle being the strongest influence in connection with accidents, however, with the restriction of being valid only for the specified age-group.

b) Remarkable was the opposite effect of the critical physical/positive emotional state on the age group above thirty. Despite a rather low significance, the inversion of the effect compared with the younger group seemed to be worth mention, supporting the possible age-dependency of biorhythms in connection with accidents.

c) Also, emotional criticality together with a negative physical state caused more accidents to happen in the age group above thirty. This supports the idea of increasing importance of the physical cycle for relatively older pilots, given there is emotional criticality (the positive physical state in connection with emotional criticality showed less than expected mishaps).

d) In the case of double criticality, the higher experience of older pilots seemed to play a role, leading to the correct interpretation of the reduced capability at such days. It is at least reasonable to argue that the younger pilot with less experience is not inclined to draw any conclusions out of "feeling really bad" at a certain day and, therefore, paying even more attention.

In order to get an impression of the nature of this correlation between the younger and the older age group, the normalized deviations from the expected values were ranked for the criticality involving states.

	Pilots Under 30		Pilots 30 & Above	
State	Deviation in %	Rank	Deviation in %	Rank
(0,0)	+ 29.14	1	- 45.53	5
(+,0)	+ 1.58	2	- 6.64	4
(-,0)	+ 0.51	3	+ 16.18	1
(0,-)	- 4.14	4	- 1.12	3
(0,+)	- 17.09	5	+ 10.61	2

Table VIII. Determination of Kendall's Tau for the Two-Dimensional Criticality States Under the Two Cycle Model (Pilots Under and Above 30 Years).

The ranking was applied such that the high positive deviations ranked first, down to the highest negative ones as last. Computing "Kendall's Tau" as a measure for the correlation showed a value $\tau = -0.6$:

State	(0,0)	(+,0)	(-,0)	(0,-)	(0,+)
Under 30	1	2	3	4	5
30 and Above	5	4	1	3	2

$$S = (0-4) + (0-3) + (2-0) + (0-1) = \underline{-6}$$

$$\tau = \frac{S}{.5\ N(N-1)} = \frac{-6}{5 \cdot 2} = -0.6;$$ significance level, associated with that correlation is 0.117.

The negative correlation was further support of the argument that the effect of biorhythmic states is reversed between younger and older age groups.

4. The Problem of the "Critical Category"

Willis [1972] defined the "Critical Category" as the period of time, which includes the day, and a 12-hour period either side of the day during which the curve or curves cross the zero line from positive to negative or negative to positive.

The concept was in so far considered to be of importance, as many of the critics of biorhythms address the matter of exact length of the cycles as well as the strict definition of a "critical day". These critics are based on arguments like the following, which were considered to be valid:

a) Biorhythmic theory proposes that two persons with the same birthday would be said to have identical biorhythmic cycles throughout their lives. However, they might be born

almost 24 hours apart: one of them ten minutes past midnight, the other one 23 hours later - but still on the same day.

b) A big problem - particularly in this data set - was the question of the different time zones. If the pilot's mishap was recorded in a different time zone than the one he was borne in, there may be differences up to several hours thus distorting the true state of his cycles at the occurrence of the mishap. Unfortunately, not enough information was obtainable to 'clean' the data. Therefore, a pilot born at the east-coast of the United States might be recorded in connection with a mishap (local time) in Vietnam or aboard a carrier in the Mediterranean, his criticality thus not correctly being evaluated.

c) Another problem occurred in the criticality definition of the 28-day emotional cycle, having its intersection from positive to negative at the end of the 14th day. Accordingly, the "critical day" occurs 12 hours before and after that point, which would require knowledge of the exact hour of the accident.

One further aspect of importance is the close resemblance of the 28-day emotional cycle and the female menstrual rhythm (the following is cited from W. P. Colquhoun, 'Biological Rhythms and Human Performance', 1971). Its resemblance to the fixed 28-day emotional cycle is striking, however, the female menstrual cycle does not have a fixed length: its <u>mean</u> is reported to be 28 days, with a range of 24 to 33 days actual length [Redgrove, 1968]. Extensive

research has been done to describe human performance (including critical incidents such as crime, suicide, accidents) during the female menstrual cycle, finding a very close fit to the general shape of the 28-day emotional cycle in biorhythmic theory. June A. Redgrove's article reports several studies which found that suicide occurs most frequently during menstruation [Rosenzweig, 1943]. Crimes occurred at an increased rate both menstrually and pre-menstrually [Dalton, 1961, Morton, 1953]. In a typing-study, the same 'division' into 4 parts like in the biorhythmic 28-day cycle was found: 1-7 days, 8-14, 15-21, 22-28 [Redgrove, 1968], and the daily variation throughout the cycle was stressed. Dalton [1964] found significance in the study of accidents falling more often in the menstruation period. In all these cases, two important aspects had been considered:

a) the individual length of the whole cycle rather than a fixed 28-day cycle;

b) the menstruation period itself is a time interval rather than a single critical day like in biorhythmic theory. Also, the cycles for one woman vary significantly. (Redgrove's article cites a study of more than 30,000 cycles with a range of ± 6 days for two successive cycles.)

Based on these considerations, the data were evaluated not only under the aspect of the criticality definitions used in the base case, but also under different definitions looking at two and three day intervals, thus defining a 'critical interval' rather than just a critical day. This analysis took

into account all the possible distortions by time zones, the poorly defined critical day of the emotional cycle (between the half-cycles), and possible individual slight variations. With that, the hypothesis could be tested, whether there was a significantly different result than for the base case. Five different criticality definitions (including the base case) were then defined, classified as 'Run 1' through 'Run 5'

Table IX. Possible Criticality Definitions.

		Cycle	Critical Days
One-day Versions	Run 1	PHYS	1,12
		EM	1,15
		INT	1,17
	Run 2	PHYS	1,12
		EM	1,14
		INT	1,17
Two-day Versions	Run 3	PHYS	0,1,11,12
		EM	0,1,14,15
		INT	0,1,16,17
	Run 4	PHYS	1,2,12,13
		EM	1,2,14,15
		INT	1,2,17,18
Three-day Versions	Run 5	PHYS	0,1,2,11,12,13
		EM	0,1,2,14,15,16
		INT	0,1,2,16,17,18

The question to be answered was: Does the significance of biorhythmic criticality as an influence on aircraft mishaps change when two or three day intervals are defined as critical, rather than one day like in the base model?

The form of the question suggested the use of an ANOVA-design, taking the "criticality-definition" as the "treatment" and then testing the hypothesis whether the effect of that treatment on the deviation from the expected number of mishaps is significant or not. The only problem with that was that the different criticality definitions (runs) were not independent from each other, because some of the critical days having been counted already for the base case model appeared again as part of a two-day or the three-day model. Therefore, the question had to be approached differently. For each of the three cycles, it was determined, how many mishaps occurred on the day before the critical day, on the critical day itself (as defined in the base model), and on the day after the critical day. Then, if one of the two-day models or the three-day model should have shown stronger significance than the one-day model, high deviations in the "day before" and "day after" were necessary to cause that effect.

In order to eliminate an influence from the fact that there are more occurrences of critical physical days because of the shorter period, etc., and, therefore, a deviation of, for example, five days has a different significance for each of the three cycles, the measure of deviation was defined as the normalized ratio

$$R = \frac{\text{Observed - Expected}}{\text{Expected}} \times 100 \quad [\%].$$

The results observed are shown in Table X.

	Day Before	Critical Day	Day After
23-day cycle	361	360	368
28-day cycle	313	318	311
33-day cycle	279	255	252

Table X. Mishap Observations for the Three Cycles in the Critical Category.

The expected numbers of mishaps for the 23-day cycle were 377.913, for the 28-day cycle were 310.429, and for the 33-day cycle 263.394. Based on that, a non-parameteric Analysis of Variance was used to test the Null-Hypothesis of no difference between the days, using R as data inputs. Before doing that, the probability of occurrence of the observation in each cell under the binomial test was computed, using the normal approximation in the already explained method.

Probability of Occurrence Under the
Assumption of no Influence from Biorhythms

	Day Before	Critical Day	Day After
23-day cycle	$P(x \leq 361) = 0.18$	$P(x \leq 360) = 0.17$	$P(x \geq 388) = 0.29$
28-day cycle	$P(x \geq 313) = 0.45$	$P(x \geq 318) = 0.34$	$P(x \geq 311) = 0.49$
33-day cycle	$P(x \geq 279) = 0.17$	$P(x \leq 255) = 0.30$	$P(x \leq 252) = 0.25$

From that point of view, whatever day was looked at in whatever cycle, there was no significance at the chosen level of 0.10. To test whether there was a difference between the three days, the value of R was tested, using a Friedman Two-Way

Analysis of Variance, based on ranks. This technique was used despite its lack of power, because the parametric ANOVA required normality and constant error variance - a very doubtful property of the data under investigation.

	Condition		
	Day Before	Critical Day	Day After
P	(-4.48) 2	(-4.74) 3	(+2.67) 1
E	(+0.83) 3	(+2.44) 1	(+0.18) 2
I	(+5.92) 1	(-3.19) 2	(-4.33) 3
R_j	6	6	6

The data points R (in parenthesis) were ranked such that, within each cycle, the highest positive deviation got rank 1, the largest negative rank 3. Under the Null-Hypothesis of no differences between the days and their mishap occurrences each rank assignment should be equally likely ($\alpha = 0.10$).

Let N = number of cycles = 3

k = number of conditions (days) = 3

Test statistic:

$$\chi_r^2 = \frac{12}{N \cdot k \cdot (k+1)} \cdot \sum_{j=1}^{k} (R_j)^2 - 3N(k+1)$$

$$= \frac{12}{3 \cdot 3 \cdot 4} \cdot (36 + 36 + 36) - 3 \cdot 3 \cdot 4 = 36 - 36 = \underline{0}.$$

Accept H_o: There is no difference in deviation between days.

The interpretation of these results was interesting insofar as the analysis showed a support of the criticality definitions in the base case, just looking at one critical

day. Further, the irrelevance of the intellectual cycle as a contributing factor to aircraft mishaps became apparent in the inconsistent deviations on the three days of the critical category, supporting its elimination from the model. Because the non-parametric ANOVA yielded non-significant results as far as differences in the deviations of each day were concerned, the choice of those with the highest relative significance yielded the actually used "critical days" of the 23 and 28 day cycles, after elimination of the 33-day cycle. The author felt, however, that these were not very powerful results and called for further analysis, as pointed out in the conclusions. The important aspect of this part of the analysis was that it turned out to be of no influence on the question under study, whether two or even three days were defined as critical.

5. The Question of Accident Type

A very important question to be answered in the study of biorhythmic influence on accidents (aircraft-mishaps) is the question to what degree the pilot was a contributing or even the only factor. The problem was that an unknown number of mishaps might have occurred in such a way that the condition of the pilot was completely unimportant because even an absolute error-free performance would not have prevented the mishap. An example for such a case might be an F-4, being struck by a lightning right at the moment of take-off, leading to an unavoidable accident. It should be mentioned that extreme care is given to the answer of the

question in how much a pilot was a contributing factor. Minute investigations in that direction are done by groups of experts, trying to take into consideration every possible factor. Too often, however, the judgement about the classification "pilot factor" is just as good as the measurement, being taken by other humans with all their possible bias and errors. The data-base for this study consisted of aircraft-mishaps, where the pilots in all cases were a contributing factor to some extent. There existed the possibility that biorhythmic criticality in its influence on accidents would show up with higher significance, if the data-base was reduced to those, where the pilot was the only cause. Unfortunately, the difficulty of classifying the mishaps remained: Did the engine fail because of a pilot error, or did the pilot react poorly after engine failure, or did a combination of unfavorable circumstances leave the pilot without the slightest chance?

Based on considerations like these, it was felt, that the data were just not suitable for an analysis of "pilot only" mishaps, which unfortunately seems to be the case for aircraft-mishaps in general. A short look at 2310 mishaps out of the total data-base, which had been categorized as "pilot factor only" under the base model showed the anticipated resemblance to the result of the total data-base investigation as shown in the following table.

To study the effect of biorhythmic criticality on aircraft-mishaps further under this aspect, the necessity of

"clean" data becomes the crucial point. Possibilities in that direction are pointed out in the conclusion.

	Number of Mishaps	
Criticality	Expected	Observed
Non-critical	1840.15	1844
Single physical	175.56	170
Single emotional	140.91	147
Single intellectual	117.81	117
Double physical/emotional	13.86	12
Double physical/intellectual	11.55	11
Double emotional/intellectual	9.24	9
Triple critical	0.92	0
TOTAL	2310	2310

Table XII. "Pilot-Factor-Only" - Cause Observed Mishaps.

IV. CONCLUSION

A. DISCUSSION

There is only little doubt left today about the factual existence of cycles of various kinds influencing human beings. Many of these cycles are well known to us, like the circadian cycle, others we are completely unaware of like the differences in the secretion of certain glands. Nevertheless, all of them do affect us in some way, as was shown in numerous experiments mostly in the medical field [Luce, 1971, Ward, 1971]. Danish endocrinologist, Dr. Christian Hamburger, showed a near-monthly cycle in the fluctuations of adrenal hormones (known as 17-ketosteroids, sex hormones that are affected by gonadal secretion and can be detected in the urine) based on daily observations for 16 years [Luce, 1971]. A wide field of 24-hour-periodic phenomena led to a completely new science already in the 1930's, called biological rhythm research (this was triggered by the discovery of a periodic alternating storage of glycogen and bile in the liver, found in 1927 by Forsgren [Ward, 1971]. Many more experiments about biological rhythms could be cited from the literature, pointing towards the causalities of these periodic alterations. The purpose of this study was to contribute to the filling of the wide gap between known medical facts in a particular field of biological rhythms and their possible influence on accidents. Not the biological rhythms themselves, and what leads to their

existence, has been under question, but in how far human error in connection with these has a high correlation to accidents (here with aircraft).

The findings of the study supported the importance of the relativity in the theory of biorhythms. Significant influence from criticality on accidents in general, as reported for different groups of people like truck drivers or agricultural workers [Thommen, 1973], could not be observed for pilots, possibly becuase of the high qualitative selectivity of this group. The irrelevance of the intellectual 33-day cycle led to its elimination from the model, supporting the results obtained by Schwing [Thommen, 1973]. A consideration of the criticality state (in the two-cycle model) of both cycles showed a high negative correlation (significance 0.117) between pilots under and above 30 years of age. This meant that the criticality state of the 23-day and the 28-day cycle had in many cases opposite effects in connection with aircraft mishaps in the mutual comparison of the two mentioned age groups. For applied purposes, a distinction according to the age of the pilot seemed justified. A significant (α = 0.03) reduction of accidents was observed for the younger pilots when a critical physical day was accompanied by a positive state of the emotional cycle, while an increase of accidents could be observed on double critical days for this age group. The exact opposite effect occurred in the case of the older group with the additional effect of an increased number of mishaps occurring on physical

critical days and a negative state of the emotional cycle. It should be noted that these effects did not show up to that extent when investigating only the state of one cycle. In the question of the "critical category" it was concluded that no significant change in the results is to be expected when looking at critical intervals of two or three days length rather than at a critical day (assuming the two-cycle model). Further research, however, was considered to be necessary for more powerful results than the ones obtained by the analysis. The author did not feel confident enough in a rigorous categorization of the data in the type "pilot factor only" caused accidents, to use the 2310 mishaps of this type for analytical purposes. Again, suggestions for further study will be given to obtain evidence about that matter.

B. AREAS OF FURTHER STUDY

As so often happens in research, the gain of a few new insights opened up more doors to the unknown, thus leading to areas of further research. Some of the ones which seemed to be most apparent are listed below.

1) The results of the investigation of the "critical category" suggested further research in the direction of the exact shape of the three cycles. A possibility is for example, counting the number of mishaps which occurred on each day of a cycle. Then, tests for uniformity of these numbers could be run, in addition to a Regression analysis trying to relate the dependent Variable Y = number of mishaps as a function of the cycle C and the day D, $1 \leq D \leq T$, where

$$Y = f(C,D), Y \geq 0,$$

and

$$T = \text{period of cycle } C.$$

Under the Null-Hypothesis as stated in this study several times, Y should be constant N/T, for a given set of N mishaps.

2) Similar to this analysis just mentioned, the idea could be extended to find this function $Y = f(C,D)$ for every possible pilot age (as far as enough data are available). This would be particularly interesting under the aspect of possible differences between these functions, depending on the pilot-age, after having found strong indications in that direction in this study. This would allow for more detailed determination of criticality influence on each specific age, provided enough data are available, which might not be the case for very young and relatively old pilots. The question of sample size becoming very crucial would require its careful determination to fulfill minimum requirements as far as both power and significance are concerned.

3) As pointed out in the attempt of analyzing those mishaps with a high degree of pilot involvement ("pilot factor only"), the classification of the data in that respect is so far not quite sufficient for statistical purposes, because too many different people are involved in this categorization process. A suggestion might be to use Statistical Decision Theory to establish criteria which would

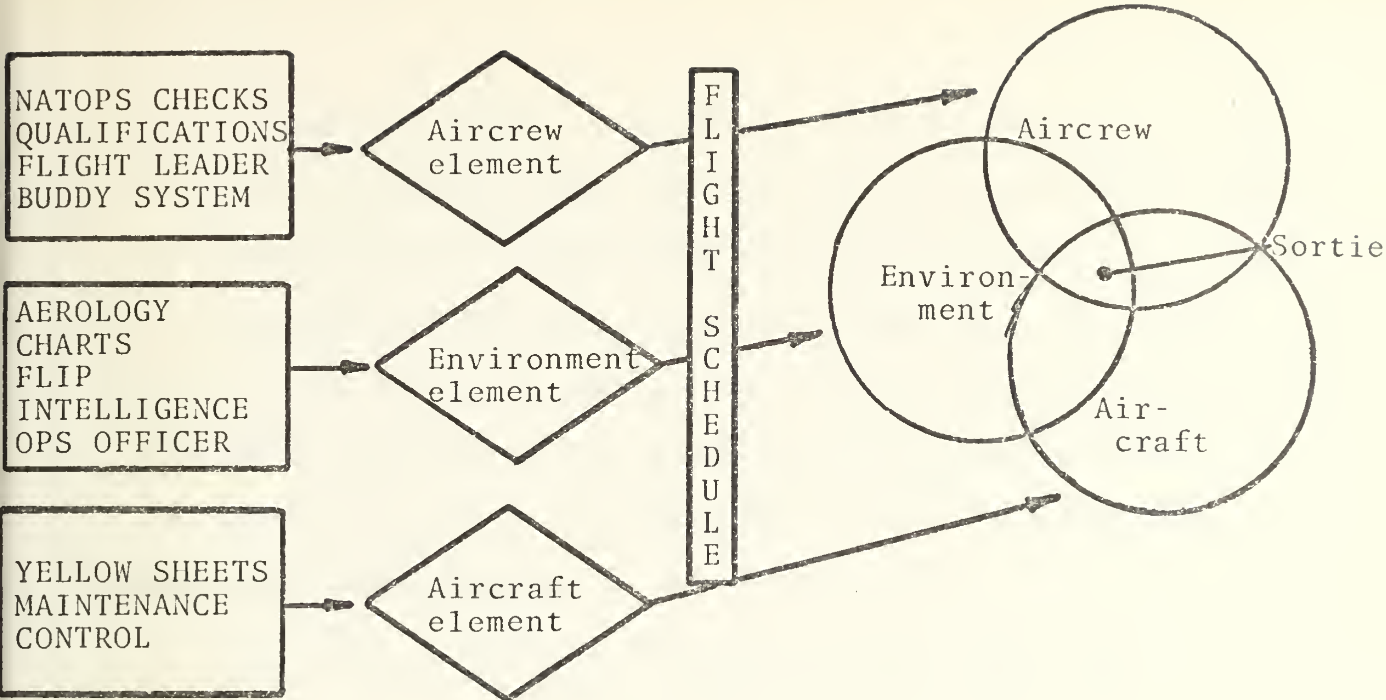
enable an investigator of a given data set, to distinguish a mishap with high enough pilot involvement from others with too many factors having contributed to the mishap. An interesting approach would be the use of signal detection theory, as described by Swets, Tanner, and Birdsall in their article 'Decision Processes in Perception' (Psychological Review, 1961). Calling all the possible mishap-contribution factors like environment, technical failures, other aircraft, etc. "noise", and the pilot's error the "signal", a policy could be established defining the circumstances under which a given mishap is called "pilot factor caused". This design also would take into account the fact that there is always "noise", that is, an accident will rarely have the pure factor 'pilot' as its only cause. Analysis of these data could then be performed to test the significance of biorhythmic criticality on aircraft-mishaps.

APPENDIX A: APPLICATION OF BIORHYTHMIC CRITICALITY AS A SUGGESTION FOR USE IN A "SORTIE SYSTEM SAFETY EVALUATION"

The concept of biorhythms should not be seen alone, but always integrated into the man-machine system under investigation. A suggestion of its possible use in military aviation (which could be easily modified for commercial flying) was considered to be illustrative for demonstrative purposes. The model just shows, at what place information about the biorhythmic state of a pilot could be utilized. In June 1973, an article in the Naval Safety Review magazine APPROACH with the title "System Safety and the Decision Maker" was presented by LCDR R. A. Hess (USN), containing a suggestion for a "Sortie System Safety Evaluation":

System Safety Evaluation

Aircrew	Environment	Aircraft
- training	- weather	-known faults
- qualifications	- terrain	-system degradation
- capability	- navaids	-fuel load
- experience	- terminal facilities	-change compliance
- attitude	- mission	-configuration
- health	- sea state	-weapons load
- anxiety	- light	-repeat gripes
- fatigue	- temperature	-quality of maintenance
	- traffic	
etc.	etc.	etc.



According to that the three elements were now rated as shown in the following table, and the scores were added to a "Sortie total".

		Outstanding	Good	Fair	Marginal
Aircrew element	ACR	5	4	3	2
Environment element	E	4	3	2	1
Aircraft element	A	3	2	1	0

	Total of	
Acceptable	8-12	
Undesirable	6-7	(Requires CO evaluation and decision)
Unacceptable	3-5	(Requires revision of elements)

In this model the importance of the human factor was recognized by giving more weight to the Aircrew element. An

improvement certainly would be, to replace the rigid number scale by a function, thus taking into account more the human complexity without taking away from the practicality. This is also the element, where the biorhythmic condition of the Aircrew would be represented, namely as one of the independent variables, influencing the dependent variable "aircrew". One very simple example for such a function might be the following:

$$ACR = f(A,E,LC,BC,Q) = \frac{1}{8}(E + A + LC + BC + Q)$$

where

- E and A like defined above;
- LC stands for "Life Changes", a concept of measuring influences from the psychological side on a scale, like death of a close relative, or many moves to different places in the past year, etc. [Rahe, 1973]. The LC-value ranges from 0 to 13.
- BC stands for Biorhythmic criticality, defined on a scale from 0 to 10. The value 0 would be assigned, if the pilot would have the most critical state with the highest accident probability, the value 10 for the most favorable state.
- Q stands for aircrews qualifications, experience, etc., and is scaled from 0 to 10.

The range of this function would be $5 \leq ACR \leq 0.125$, which would still keep computations simple enough, but the total would now be a little bit more sensitive to slight differences within the aircrew element. Defining the region

between 5 and 8 as the one, where CO evaluation and decision is required, the "poor values" of the aircrew element now fall into this range, which seems to make sense. A "marginal" rating of the aircrew element should not lead to an "acceptable" total, even if everything else looks outstanding. Also, the system reflects the very high requirements for the aircrew element, if environment and aircraft are marginal. Again, it should be emphasized that this was just considered to be a suggestion for the possible application of Biorhythms in aviation, and that more research in the suggested direction needs to be done.

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